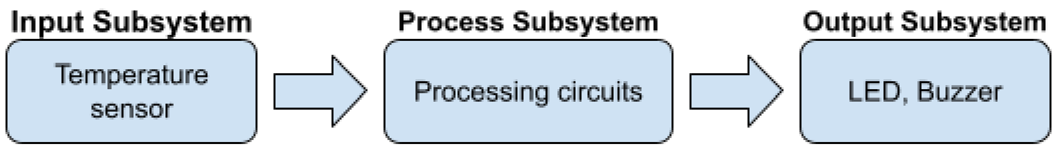
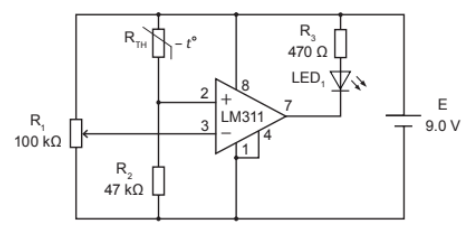
Electronics notes (Analogue) (pm something3009 on discord if there are any errors)

Chapter	**Content**	**Examples**
Chapter 1: Electronic Systems	Main parts of electronic systems: Input Subsystem, Process Subsystem, Output Subsystem	Calculators, Microphones, hairdryer, ect
	Block Diagram (eg thermometer)  	
	How electronic systems are presented: Block Diagrams (see above): Provides overview of system Circuit Diagram: Gives information on how the circuit is built, and contains values, components and the way it is connected	Circuit Diagram: 
	How does information flow in electronic systems? Electronic systems can only process info in the form of electric signals (voltage/currents that carry info) non electrical info(input) -> Electrical info (process) -> non electric info (output)	Analogue signals: 0 to 5V Digital signals: 0 OR 5V
Chapter 2: Current Electricity	Voltage: Comes in 2 forms Electromotive force (EMF): Total voltage of batteries connected in series or parallel Effective EMF in series = $E_1 + E_2 + E_3 + \ ... + E_n$ Effective EMF in parallel = same with all other batteries in parallel (usually of same voltage) Potential Difference (P.D.): Work done to drive a unit charge through a component or in between 2 points in a circuit	

	Current Rate of flow of Electric Charge Conventional current flow: From positive to negative terminal (mostly used) Electron flow: From negative to positive terminal $I = \frac{Q}{t}$ I - Current (A) Q - Charge (Columb) (C) t - Time in seconds (s) * Current rating: Maximum current a conductor can carry without overheating or being damaged	
	Resistance A measure of how difficult it is for a current to flow through a component $R = \frac{V}{I}$ R - Resistance (Ohm) (Ω) V - Voltage across component (V) I - Current (A) Ohm's law Current in a metallic conductor is directly proportional to P.D. across conductor (Linear I-V graph, start from origin) Non-ohmic conductors are not linear or not starting from the origin	Ohmic conductors: Resistor Non-Ohmic conductors: Filament Bulb, Semiconductor Diode
	Heating effect of Current Heat is produced when current flows through a component Heat is bad as it can cause electronic components to overheat and be damaged, energy is also wasted Power: Rate of Energy conversion $P = IV$ or $P = \frac{E}{t}$	

<table>
<tr><td></td><td>Formula can be rearranged to $P = I^2R$
or $P = \frac{V^2}{R}$
V - Voltage across component (V)
I - Current (A)
R - Resistance (Ohm) (Ω)
E - Amount of energy converted (J)
t - Time in seconds (s)

Power rating: Maximum power at which a component can be used without being damaged
*Pick power rating of 2x the calculated value</td><td>If power dissipated is 0.20W, pick resistor with 0.5W power rating</td></tr>
<tr><td></td><td>Energy
$E = VIt$
E - Amount of energy converted (J)
V - Voltage across component (V)
I - Current (A)
t - Time in seconds (s)

Energy efficency: The percentage of input energy that is converted to useful energy
Efficiency = useful power output/power input x 100%</td><td></td></tr>
<tr><td>Chapter 3: Resistors</td><td>Resistance of a conductor is affected by 4 factors
- Resistivity of material
- Length of conductor (Longer length, higher resistance)
- Cross-Sectional area of conductor (Larger cross-sectional area, lesser resistance)
- Temperature
Formula: $R = \frac{\rho l}{A}$
R - Resistance (Ohm) (Ω)
P - Resistivity of material (Ωm)
l - Length of material (m)
A - Cross sectional area (m^2)</td><td></td></tr>
</table>

<table>
<tr>
<td rowspan="2"></td>
<td>Types of resistors: Fixed resistors,
Variable resistors

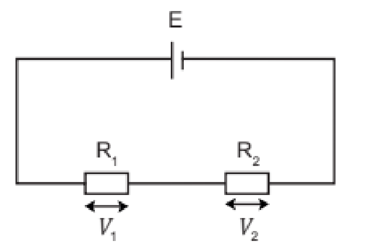
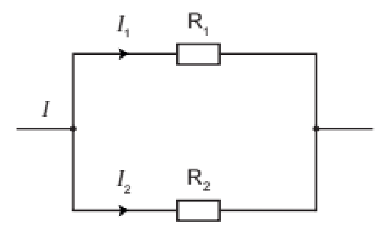
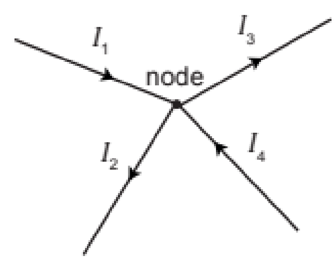
Fixed resistors: Carbon, Wire-wound
Differences:
<table>
<tr><th>Carbon</th><th>Wire-wound</th></tr>
<tr><td>Low power applications</td><td>High-power applications</td></tr>
<tr><td>Low temperature stability</td><td>High temperature stability</td></tr>
<tr><td>Typical power rating range of 0.1W - 2W</td><td>Typical power rating range of 2W - 500W</td></tr>
<tr><td>Low cost</td><td>High cost</td></tr>
</table>

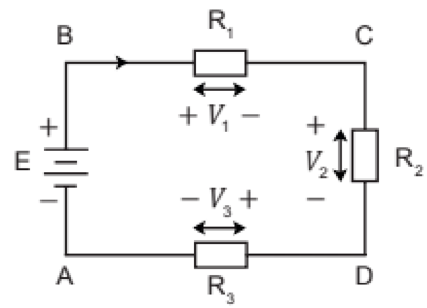
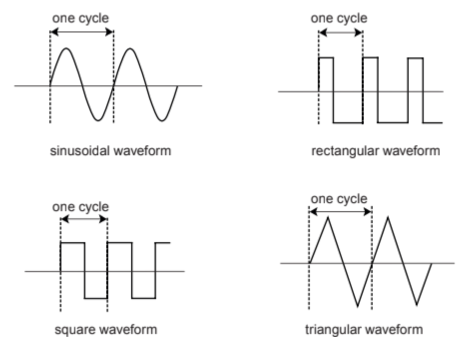
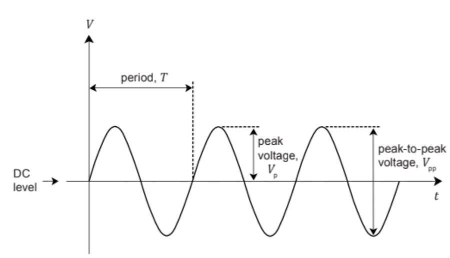
Variable resistors: Trimpot, Potentiometer. ect</td>
<td></td>
</tr>
<tr>
<td>How to determine value of resistor:
Resistor Colour Code: Series of 4 coloured bands on Carbon resistor
From left to right:
1st and 2nd band: Number
3rd band: Multiplier (no. of 0)
4th band: Percentage tolerance (eg ±5%)

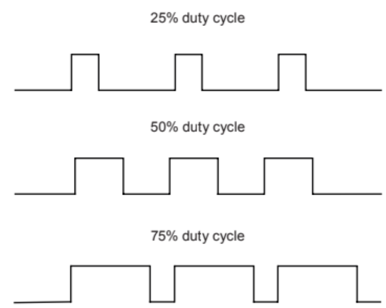
E24 series: Calculate value needed, then choose a value closest to the calculated value from the E24 series
*Selection of Resistors:
- For non-BJTs, pick value more than calculated one (reduce current to prevent overloading/damage)
- For BJTs, pick value less than calculated one (increase current flowing through transistor before BJT, make IB large enough to push BJT to saturation)</td>
<td>Resistor with band colours yellow purple orange gold: 47kΩ ±5%

If a 124Ω resistor value is calculated, use a 130Ω resistor from E24 series</td>
</tr>
</table>

	Resistors in series/parallel In series: $R_{eff} = R_1 + R_2 + \ ... + R_n$ In parallel: $\frac{1}{R_{eff}} = \frac{1}{R_1} + \frac{1}{R_2} + \ ... + \frac{1}{R_n}$	
	Power rating (Resistors) If temperature is high enough, can cause resistor to overheat (damage resistor)	Resistor with power rating of 0,25W can only withstand 0.25W It is good practice to pick power rating 2x of calculated value (eg 0.5W)
Chapter 4: Circuit Theories	Common terms used to describe a circuit: Circuits - Consists of electrical components connected together with wires, provides one or more paths for current to flow Source - It provides the e.m.f. needed to move electric charges around the circuit. Load - A component which converts electrical energy supplied by a source into other forms Open/Closed circuit - A circuit without/with a continuous path linking the positive terminal to the negative terminal of a source. Short Circuit- -A low-resistance path that is usually undesirable and harmful. Overloading - occurs when current exceeds current rating	

	Voltage and current in series and parallel Voltage/Current in series: $V = V_1 + V_2 + V_3$ $I = I_1 = I_2$ Voltage/Current in parallel: $V = V_1 = V_2 = V_3$ $I = I_1 + I_2 + I_3$	
	Voltage/Current Divider Voltage Divider: $V_1 = \frac{R_1}{R_1+R_2} \times E$ Current Divider: $I_2 = \frac{R_2}{R_1+R_2} \times I$	 
	Kirchhoff Current/Voltage Law KCL: Sum of all current entering and leaving a node = 0, current that enter the node is positive, current that leaves the node is negative	 $I_1 + I_4 = I_2 + I_3$ $0 = I_1 + I_4 - I_2 - I_3$

	KVL: Sum of all voltages in closed loop = 0, voltage increase in loop direction is positive, voltage decrease in loop direction is negative * When no V, use IR as substitute	 $E = V_1 + V_2 + V_3$ $0 = E - V_1 - V_2 - V_3$
Chapter 5: Alternating Currents	Direct Current (DC): Current flows in 1 direction, terminals do not change polarity Alternating Current (AC): Current changes directions periodically (Terminals change polarity)	DC: Batteries AC: AC Generators
	Types of AC Waveforms Periodic: Sinusoidal, Rectangular, Square, Triangular Non-Periodic: Waveforms that do not repeat themselves (eg microphone signals) Waveforms are generated by Function Generator, waveforms can be observed via **Oscilloscope**	Periodic waveforms 
	Describing AC waveforms DC Level: Voltage level which waveform oscillates about Peak voltage (V_P): Highest point from DC level Peak-to-Peak voltage (V_{PP}): Lowest to highest point	

	Duty cycle: Percentage of rectangular waveform when waveform is at higher level Period: Time taken to complete 1 cycle of waveform Frequency: Number of complete cycles created every second Formula: $f = \frac{1}{T}$ f - Frequency (Hz) T - Period (s)	
	Duty cycle is the percentage of the period of a rectangular waveform when it is at the higher voltage level Power supplied to a device can be controlled by adjusting Duty cycle Duty cycle = $\frac{t_{high}}{T} \times 100\%$	
Chapter 6: Capacitors	Capacitors consists of 2 metal plates separated by a Dielectric Dielectric: insulating material separating two metal plates Charging: Safety precautions: connect a resistor between the 2 metal plates to discharge. It cannot be discharged directly as it will cause a large current spike which will damage the capacitor	Uses of Capacitors: Voltage-Smoothing (Full-wave rectifier), Coupling Capacitors (BJT amplifier)
	Determining how much charge a Capacitor can store $C = \frac{Q}{V}$ C - Capacitance (F) Q - Charge stored (Columb) (C) V - Voltage (V)	

<table>
<tr><td></td><td>Factors affecting capacitance:
- Area of metal plates (larger = more capacitance)
- Distance separating plates (longer, less capacitance)
- Material used for Dielectric</td><td></td></tr>
<tr><td></td><td>Types of Capacitors: Polarised, Non-polarised

Electrolytic (Polarised): Short leg (-ve), -ve sign side, values on capacitor

Ceramic (pF) (Non-polarised): No polarity
To identify value: first 2 digits in pF, third digit multiplier (no of zeros after the 2 digits)

Difference:
<table>
<tr><th>Polarised</th><th>Non-polarised</th></tr>
<tr><td>Have large capacitances</td><td>Have small capacitances</td></tr>
<tr><td>Have fixed positive and negative terminals</td><td>No fixed positive or negative terminals</td></tr>
<tr><td>Typically larger in size</td><td>Typically smaller in size</td></tr>
</table>

E24 series: Calculate value needed, then choose a value closest to the calculated value from the E24 series (Similar to resistors)

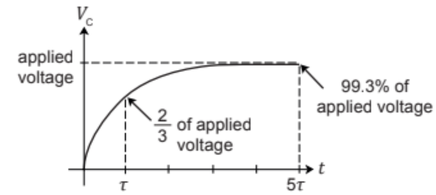
Maximum working voltage: Voltage applied on capacitor must not exceed or capacitor may be damaged</td><td>472 is 4700pF

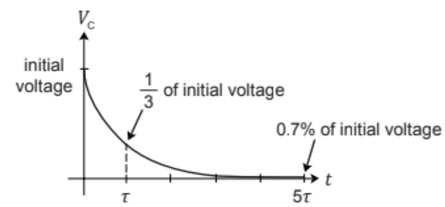
If a 467nF capacitor value is calculated, use a 470nF capacitor from E24 series</td></tr>
<tr><td></td><td>Capacitors in series/parallel

In series:
$\frac{1}{C_{eff}} = \frac{1}{C_1} + \frac{1}{C_2} + \dots + \frac{1}{C_n}$</td><td></td></tr>
</table>

<table>
<tr>
<td></td>
<td>In parallel:
$C_{eff} = C_1 + C_2 + \ ... + C_n$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RC Circuits
$\tau = RC$
τ - Time constant in seconds (s)
R - Resistance (Ω)
C - Capacitance (F)

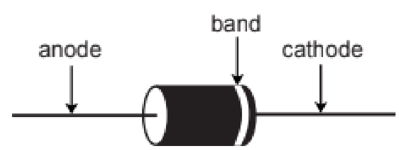
Resistor affects charging/discharging time of a capacitor
Determines charging/discharging time of capacitor

Charging/discharging:
<table>
<tr><td>Time</td><td>Charging</td><td>Discharging</td></tr>
<tr><td>τ</td><td>$\frac{2}{3} V_{cc}$</td><td>$\frac{1}{3} V_{cc}$</td></tr>
<tr><td>5τ</td><td>Fully charged</td><td>Fully discharged</td></tr>
</table>
</td>
<td>Charging graph:


Discharging graph:


</td>
</tr>
<tr>
<td>Chapter 7: Semiconductor Diodes</td>
<td>Structure of a Diode

Types of Semiconductors after Doping: N-type, P-type
N-type: rely on negative charges to conduct (Cathode)
P-type: rely on positive charges to conduct (Anode)
They are joined together to form a PN Junction Diode

Anode(+): side without band
Cathode(-): side with band</td>
<td>

</td>
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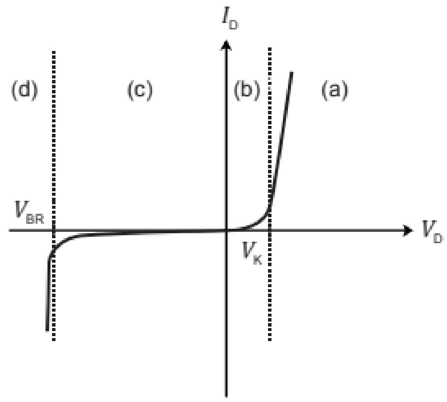
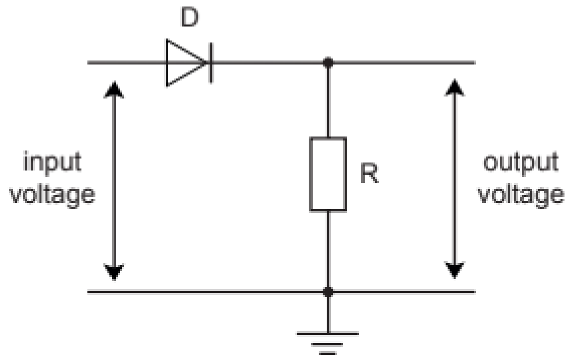
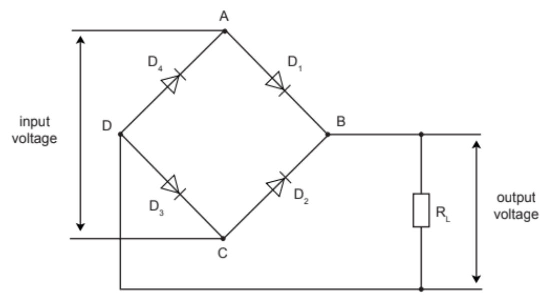
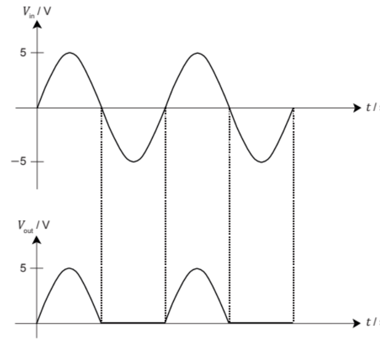
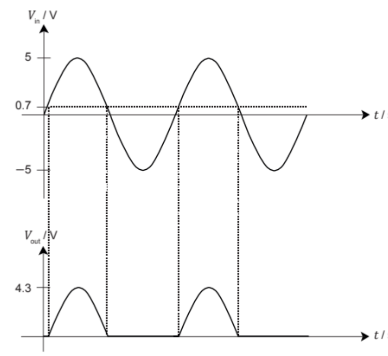
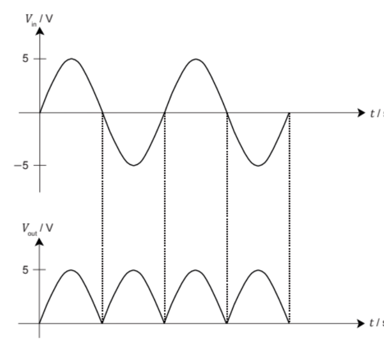
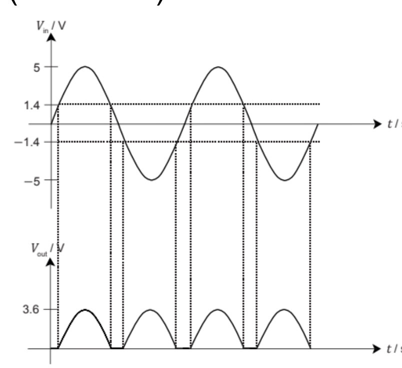
<tr>
<td></td>
<td>Behaviour of a Diode

Forward-biased mode: Current can pass through easily</td>
<td></td>
</tr>
</table>

	Reverse-biased mode: Does not allow current to pass through easily Ideal Diode: Forward-biased is perfect conductor (0 resistance), Reverse-biased is perfect insulator (infinite resistance) Practical Diode (normal, LED, Zener) has 4 operating regions:  Forward-biased (a): Current flows through diode Knee Voltage V_F (b): minimum amount of voltage needed for current to flow through diode (Usually 0.7V) Reverse-biased (c): Most current cannot flow through diode (have reverse leakage current) Breakdown voltage (d): current rapidly flows at opposite direction; can damage Diode Resistor should be connected in series with diode (Current-limiting resistor) * Resistor must be more than calculated value when selecting from E24 series	

	Rectifiers Half-wave rectifier: Only positive half of output passes through  Full-wave rectifier: Output remains positive  * Practical diodes - account for Knee voltage (Vk) when drawing output waveform graph	Ideal Diode graph (Half-wave)  Practical Diode graph (Half-wave)  Ideal Diode graph (Full-wave)  Practical Diode graph (Full-wave) 

LEDs
How to identify: Short lead/flat side is cathode pin (-)

Reasons to use LEDs
- Longer lifespan, better energy efficiency

Disadvantages:
- More costly than incandescent light bulbs

* Connect LEDs in series with a current-limiting resistor

Value of current limiting Resistor:

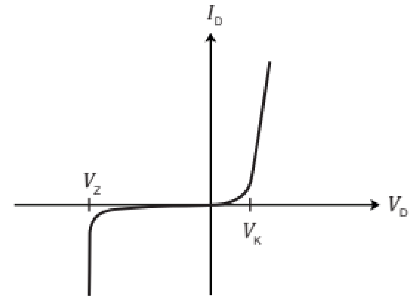
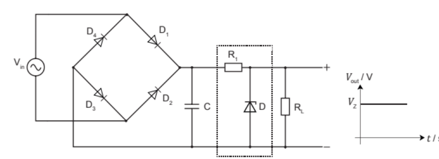
$$R = \frac{V - V_F}{I}$$

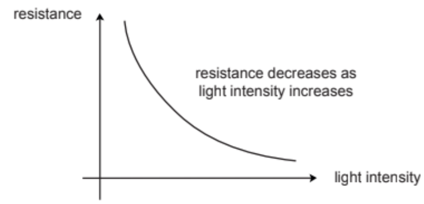
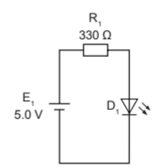
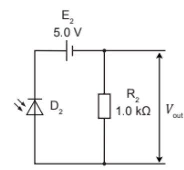
R - Resistance (Ohm) (Ω)
V - Voltage source (V)
V_F - Forward Voltage (V)
I - Current (A)

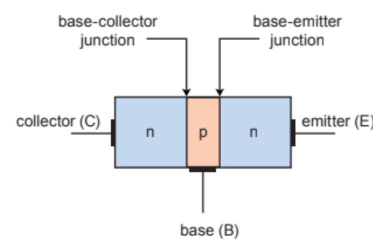
7-Segment Display
Consists of 7 segments with a decimal point

It has 2 types: Common-Anode and Common-Cathode

	Common-Anode (CA)	**Common-Cathode (CC)**
COM Pins	To V_{CC}	To GND (0V)
Segments (On)	To GND (0V)	To V_{CC} through resistors
Segments (Off)	To V_{CC} through resistors	To GND (0V)

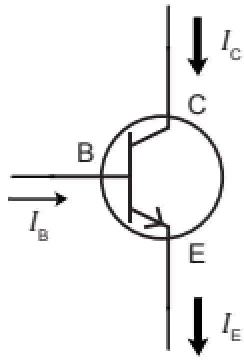
	Zener Diode Similar to normal Diode but can operate in breakdown region In breakdown region, voltage across Zener diode becomes V_Z Analysis of circuit with Zener Diode 1. Voltage-Divider to compare voltage with V_Z (Measure voltage across R_L) When V < V_Z, V_{out} = 0V When V > V_Z, V_{out}= V_Z (Voltage across load also same) 2. Power dissipated in Zener Diode If not in breakdown, P = 0W If in breakdown, $P = V \times I$ (V_Z x Current across load) Applications on Rectifier (Full-Wave): - Capacitors to smoothen output voltage waveform (unable to keep up with fast-changing output of rectifier, hence output varies over a smaller range) - Zener Diode to hold output voltage at V_Z (become steady DC voltage)	Characteristic Graph  
Chapter 8: Input and Output Transducers	Transducers Input Transducers: Convert non-electrical information/quantities into electrical signals/quantities (Sensors) Output Transducers: Convert electrical signals/quantities into non-electrical signals/quantities	Input Transducers: Thermistor, LDR, IR and Photodiode, ect Output Transducers: Motor, Buzzer, Speaker, ect
	Thermistors/LDRs Thermistor: 2 Types - PTC (Positive temperature coefficient): When temperature increase, resistance increase	NTC Thermistor/LDR Graph:

	(Resistance proportional to temperature) - NTC (Negative temperature coefficient): When temperature increase, resistance increase (Resistance inversely proportional to temperature) * NTC mostly used Light-Dependent Resistor (LDR): When Light intensity increase, resistance decreases (Resistance inversely proportional to Light intensity) Both are commonly used in Voltage-Dividers	
	IR Diode and Photodiode IR diode - produces IR rays Photodiode - recieves IR rays (allow current to flow through) * Photodiode is to be connected in Reverse-Biased Applications: Counter for items passing through, ect	How to use: 
	Microphone (has positive/negative terminals) Converts sound energy to electrical energy shorter probe is -ve terminal Buzzer (has positive/negative terminals) Converts electrical energy to sound energy shorter probe is -ve terminal	

	Loudspeaker Converts electrical energy to sound energy * requires an amplifier to produce sound DC Motors Converts electrical energy to mechanical energy Electromechanical Relays Uses electromagnets to switch on other circuits comes in SPST and SPDT (SPDT: has NO (Normally open) and NC (Normally closed)) Allows low-power circuits to switch on high-power circuits * Both DC Motor and Electromechanical Relay requires a Flyback Diode to prevent damage Flyback Diode: Protect the transistor from a large negative voltage spike when it is turned off	
Chapter 9: Bipolar Junction Transistors	BJTs It consists of 3 layers of Semiconductors arranged in either PNP or NPN Centre layer is known as the Base (B) while the thicker ends are known as the Collector (C) and the Emitter (E) *BJTs can be damaged if wrongly connected, so refer to Datasheet for pin configurations Structure: P-type Semiconductor sandwiched by N-type Semiconductor (NPN) or Vice Versa (PNP) How it works: Smaller current at Base allows a larger current to flow from Collector to Emitter	NPN BJT Structure 

Analysis of BJT

Current



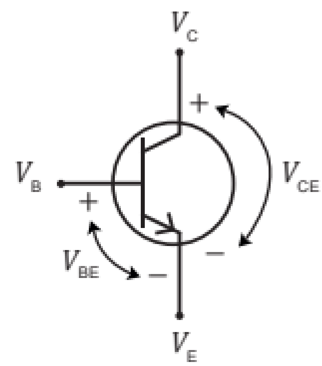
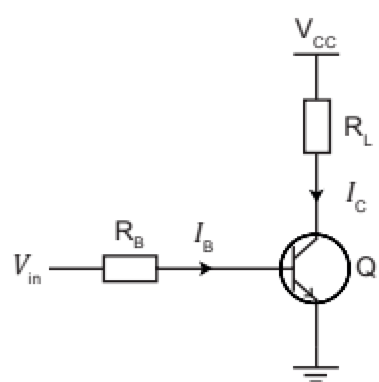
I_C - Collector Current
I_B - Base Current
I_E - Emitter Current

when
I_B = 0A, I_C and I_E = 0A, V_{CE} = V_{CC} (Cutoff region)
when I_B increases, I_C and I_E increases (Active region)
after I_B reaches a certain level (Saturation region), I_C and I_E remains nearly constant at maximum, V_{CE} reaches saturation value

$$I_E = I_B + I_C$$

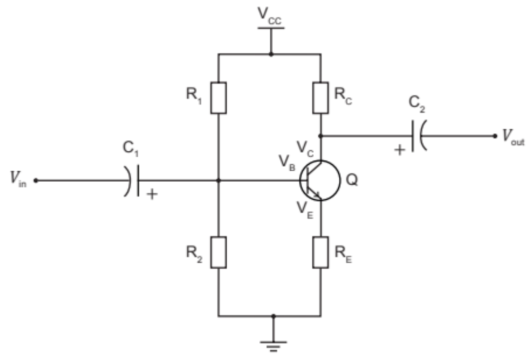
DC current gain

$$\beta_{DC} = \frac{I_C}{I_B}$$

	Voltage  Base-Emitter voltage (V_{BE}) Voltage across base and emitter To allow current to flow from base to emitter, V_{BE} must be larger that V_F (Base activation voltage) if not I_B = 0A Collector-Emitter voltage (V_{CE}) Voltage across collector and emitter	
	BJT as a switch/driver  Advantages Switch: Faster switching speeds, no wear and tear, no contact bounce (learn at Chapter 13) Driver: allow smaller current to drive a load that needs large current	

	Analysis (To find resistance R_B) * $V_{CE(sat)}$, R_C , β_{DC} , V_{BE} given Step 1: Use an suitable value of V_{CC} Step 2: Determine $I_{C(sat)}$ $I_{C(sat)} = \frac{V_{CC} - V_{CE(sat)}}{R_C}$ (Assume I_C = $I_{C(sat)}$ and V_{CE} = $V_{CE(sat)}$) * If any other components above Collector of BJT, subtract their voltages on the numerator) Step 3: Find I_B $I_B = \frac{I_C}{\beta_{DC}}$ Step 4: Find R_B $R_B = \frac{V_{in} - V_{BE}}{I_B}$ R_B value from E24 must be lower than calculated value (higher value = R_B may not be big enough) * R_B acts as current-limiting resistor, prevent I_B from being too large and damaging BJT	

BJT as a amplifier



* Capacitors (Polarised) are coupling capacitors
(allow AC signals to pass through but not DC voltages)

Analysis
(To find the following)
* V_{BE} given

V_B :

$$V_B = \frac{R_2}{R_1 + R_2} \times V_{CC}$$

(Voltage-Divider)

V_E :

$$V_E = V_B - V_{BE}$$

I_E :

$$I_E = \frac{V_E}{R_E}$$

I_C : assume $I_C = I_E$

V_C :

$$V_c = V_{cc} - I_c R_c$$

	V_{CE} : $$V_{CE} = V_C - V_E$$ $\|A_V\|$ (Voltage gain): Either $$\|A_V\| = \frac{V_{PP}\,Output}{V_{PP}\,Input}$$ Or $$\|A_V\| \approx \frac{R_C}{R_E}$$ *Output waveform is inverted Capacitor in parallel to R_E (C_3): Bypassed capacitor to increase voltage gain of amplifier	
	Darlington Pair 2 BJTs connected together DC current gain of Darlington pair = β_{DC} of both BJTs multiplied Advantages: Creates a larger current gain than a single BJT Disadvantages: - Slower switching speeds of BJTs - Base activation voltage is doubled - Bigger voltage drop	